

The State of Play US Space Systems Competitiveness

Prices, Productivity, and Other Measures of
Launchers & Spacecraft

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Purpose

- Collect space systems cost and related data (flight rate, payload, etc.) over time
 - Gathers only **public** data
 - Non-recurring **and** recurring
 - **Minimal data processing**
 - A few adjustments, mostly for apples to apples comparisons
 - Inflation to current year dollars
 - Same orbit, etc.
 - Graph, visualize, add **context**
 - Focus on US space systems **competitiveness**
 - **Keep fresh** – update as data arises, launches occur, etc.
 - Keep fresh – focus on **recent data, indicative of the future**

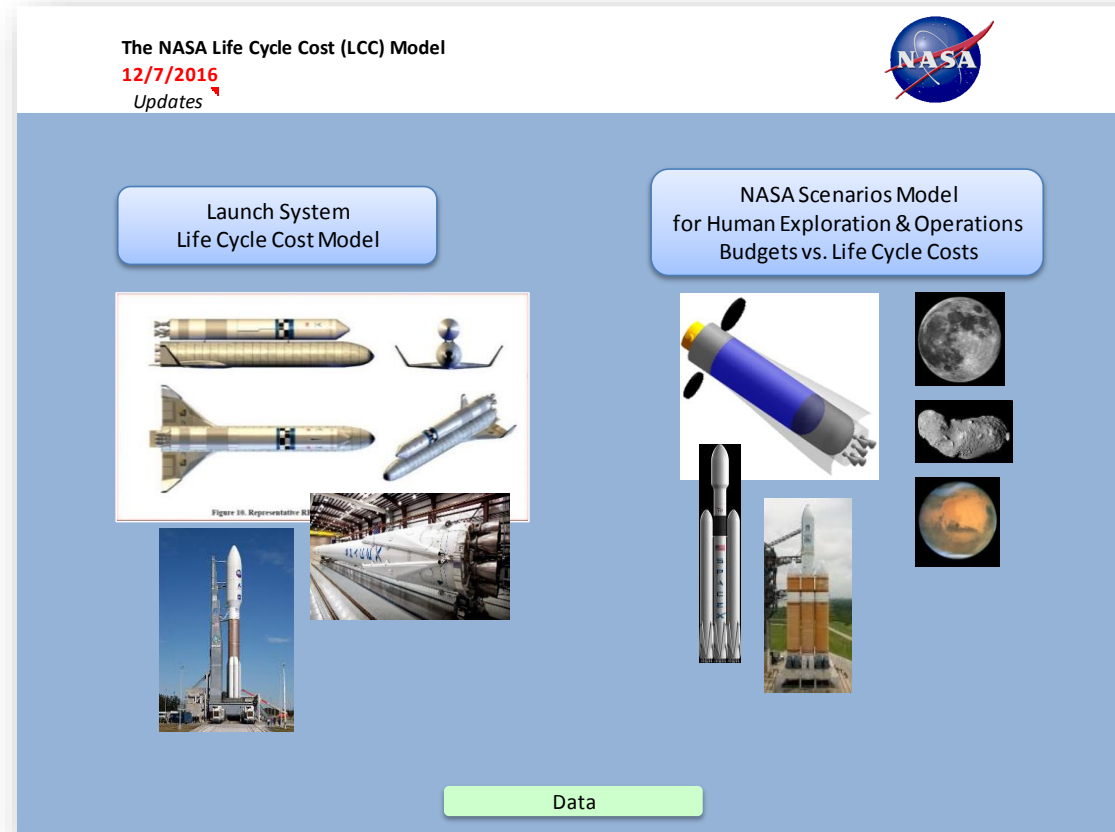
Caveats & Terminology


- The “price” to a customer is the “cost” to the customer (NASA, DoD, NRO, private sector, etc.)
 - Other government agency “costs” are personnel, government management, etc.
 - Occasional “asterisks” – included or not
- Uncertainties are inevitable
 - Anecdotal evidence some launch pricing actually higher than publicly announced (Russia/Proton, etc.)
 - Some public data is processed more – different contracts, phases, multiple partners, not yet final, age of the data, etc. (Apollo, Commercial Crew, SLS, Orion, etc.)

Source Data

Source data for this report is available in the NASA Life Cycle Cost (LCC) Model

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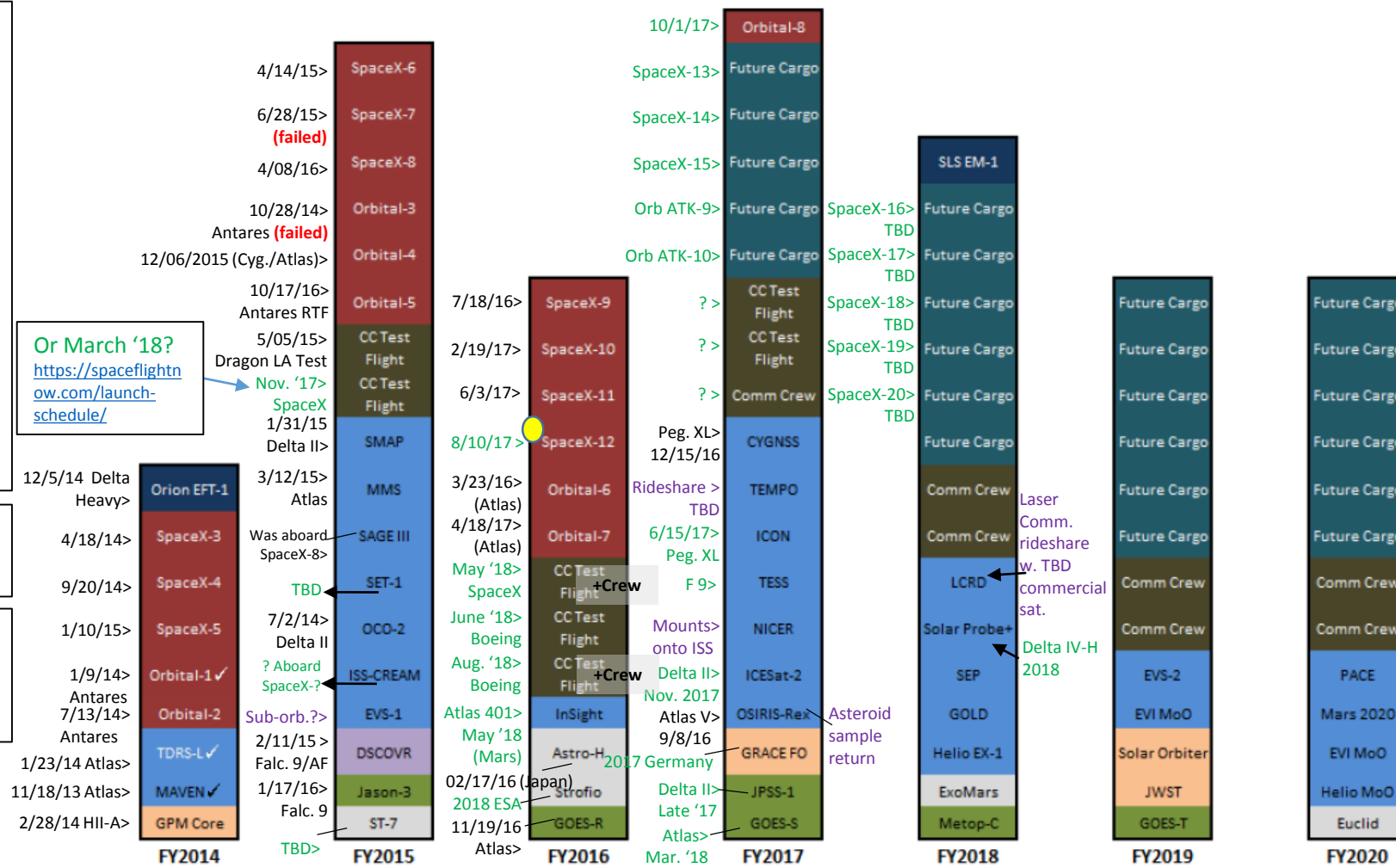


SpaceX
10 Falcon 9 (7 commercial, 2 ISS cargo, 0 NASA, 1 DoD)
Landing Success / Attempts
% Sea / %Land / %Average
62% / 100% / 72%

Or March '18?
<https://spaceflightnow.com/launch-schedule/>

● = Next
Green = Planned
Black = Actual

1st Falcon Heavy
Flight Demo TBD
Mid 2017?



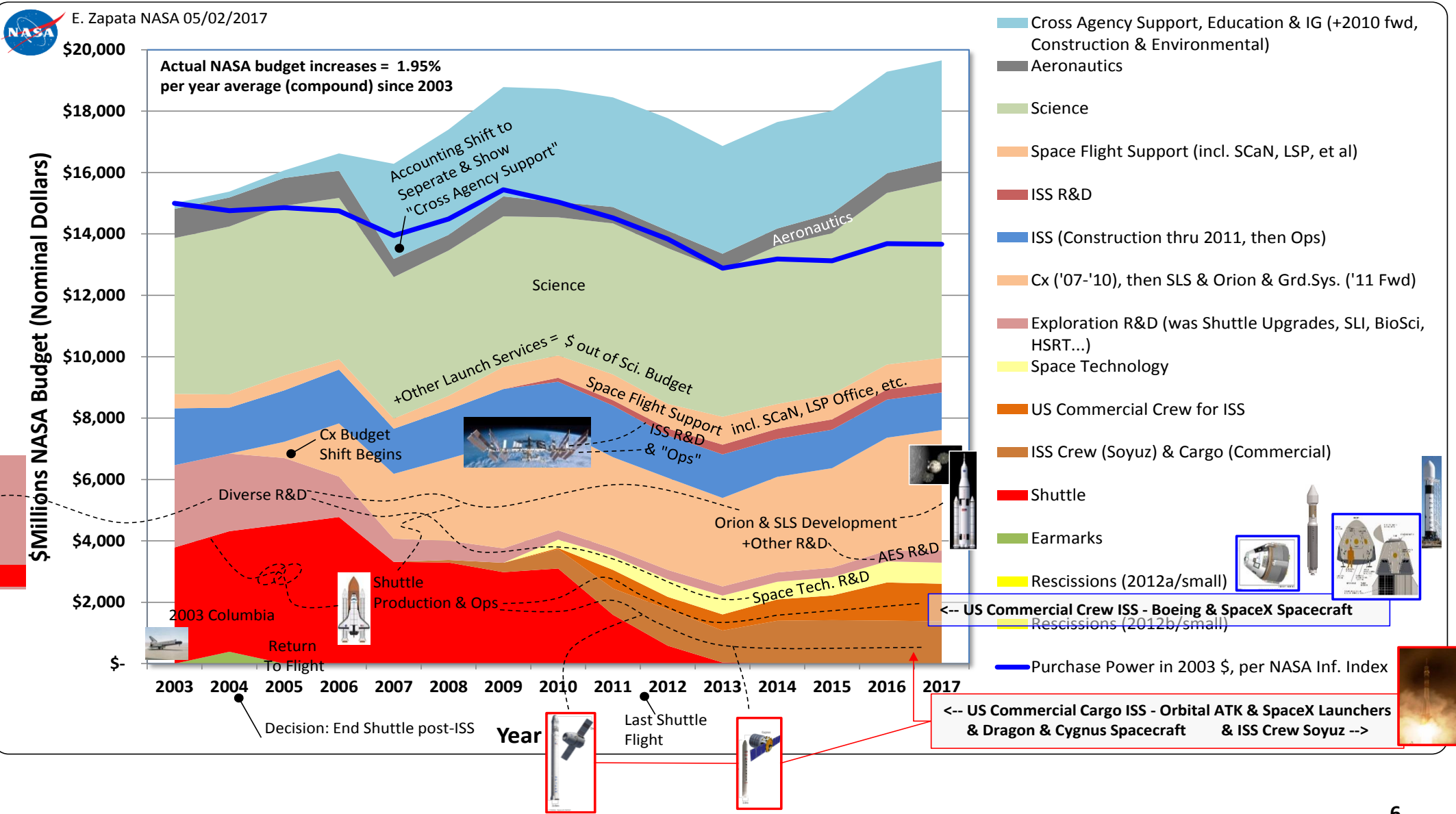
1st SLS Demo Flight **TBD.**
2019

<https://spaceflightnow.com/2017/04/28/nasa-confirms-first-flight-of-space-launch-system-will-slip-to-2019/>

“The uncrewed Orion will travel into Distant Retrograde Orbit, breaking the distance record reached by the most remote Apollo spacecraft, and then 30,000 miles farther out (275,000 total miles). The **mission will last 22 days** and will test system readiness for future crewed operations.”
-as of 4/9/2016

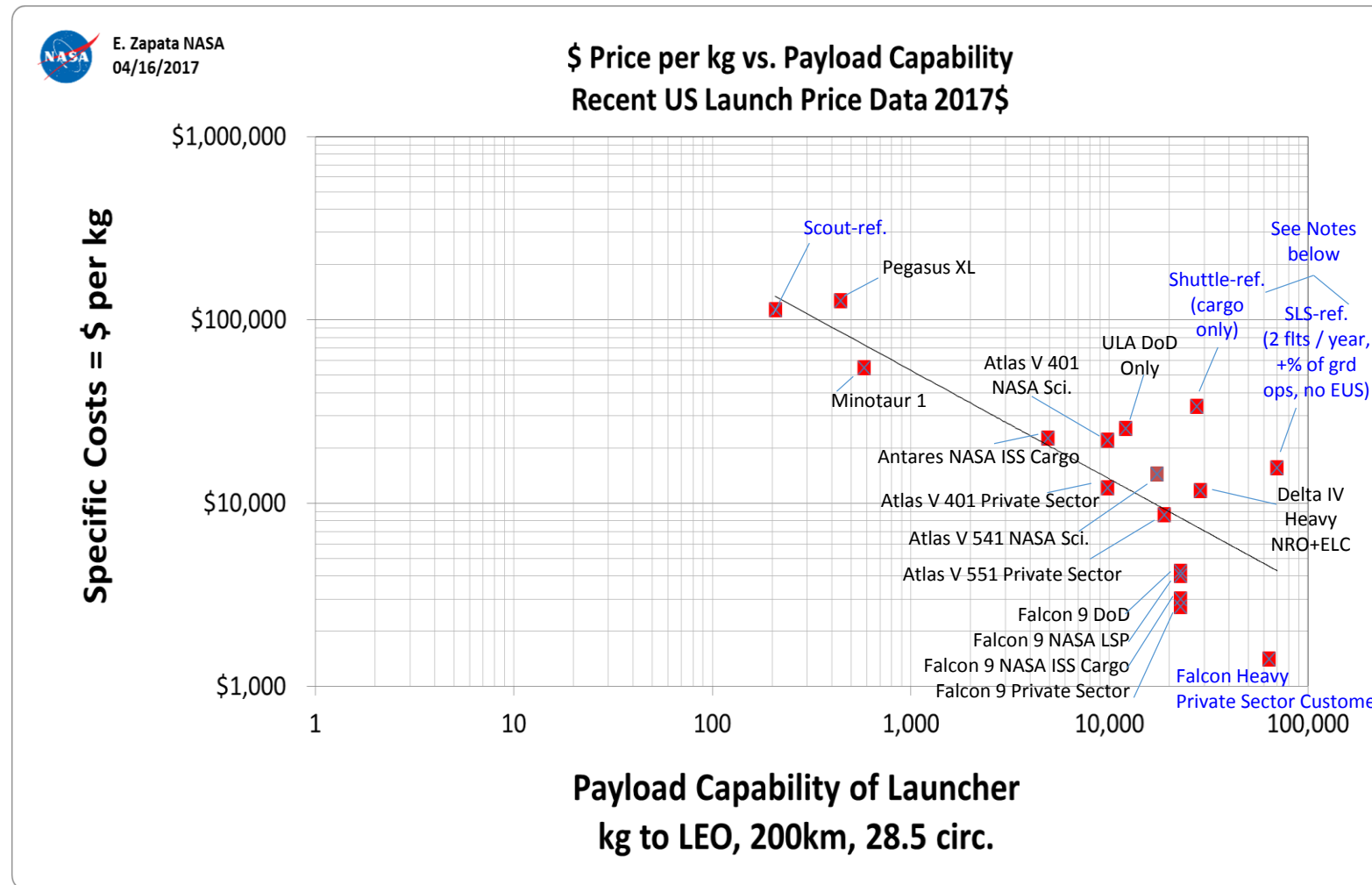


The NASA Budget – Purchase Power Drop Since 2003 = 9%



Recent Launch Prices as \$/kg of Payload (2017\$)

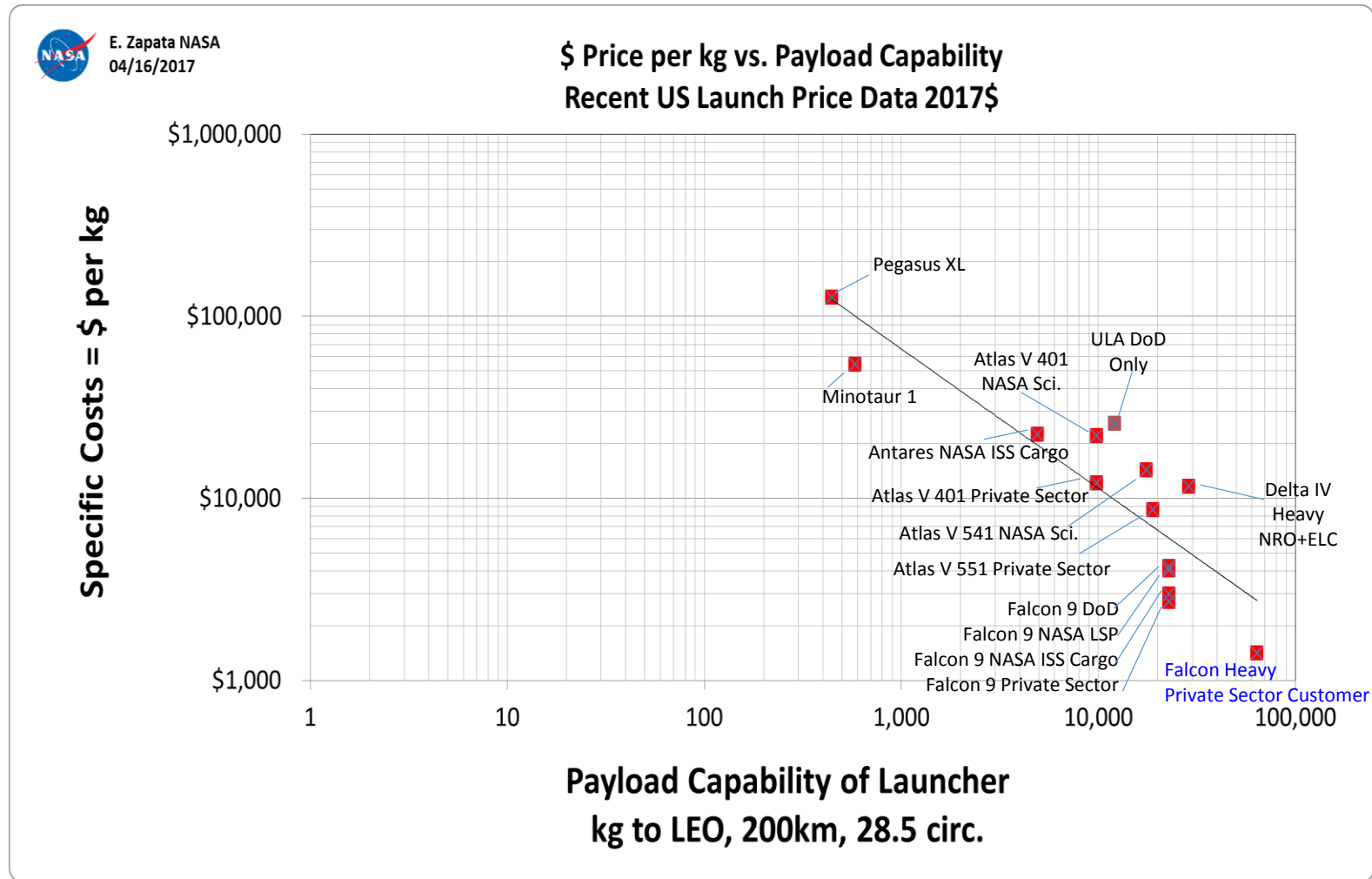
US Medium Launch + Scout, Shuttle, SLS, Falcon Heavy



- The line is a power curve fit ONLY to the points indicated with->
- For NASA and DoD, data are prices to the government, that is procurement costs only, excluding government management, personnel and related.
- For the Space Shuttle, to give a more consistent CARGO comparison, total recurring costs from life cycle cost data (1983-2013) were adjusted to remove crew at a Soyuz price rate, NASA management (civil service) and related were removed to leave procurement dollars only, and R&D years 1981-1982 were excluded as non-operational. Similarly, for SLS the NASA management (personnel) and related costs are also excluded, but unlike Shuttle, ground ops are excluded.

Recent Launch Prices as \$/kg of Payload (2017\$)

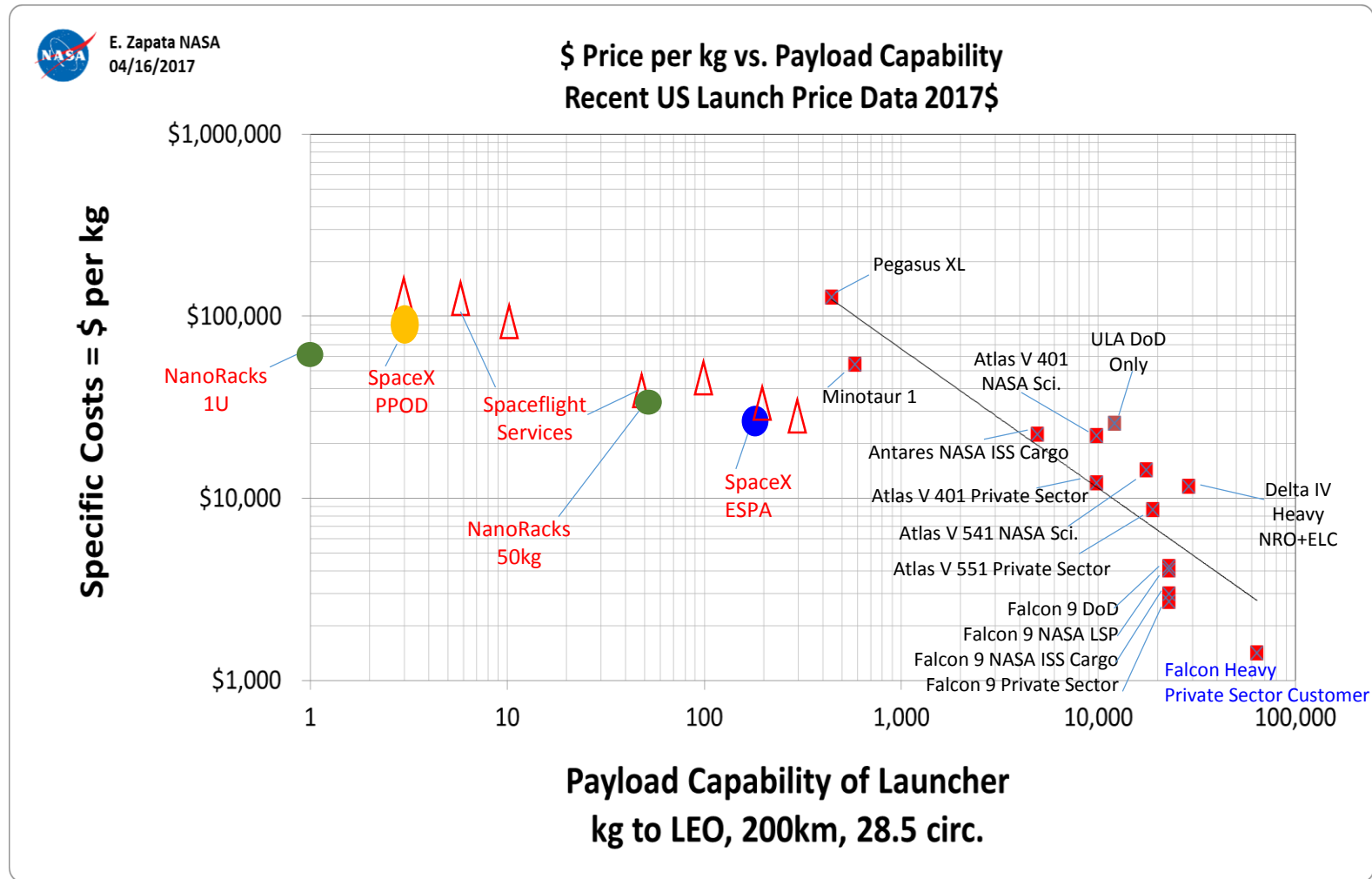
US Medium Launch - NO Scout, Shuttle, SLS



Recent Launch Prices as \$/kg of Payload (2017\$)

With Available US Small Launch / Services

- NanoRacks as of 12/7/2015
- △ SpaceFlight Services as of 12/7/2015
- See Backup slides for data sources



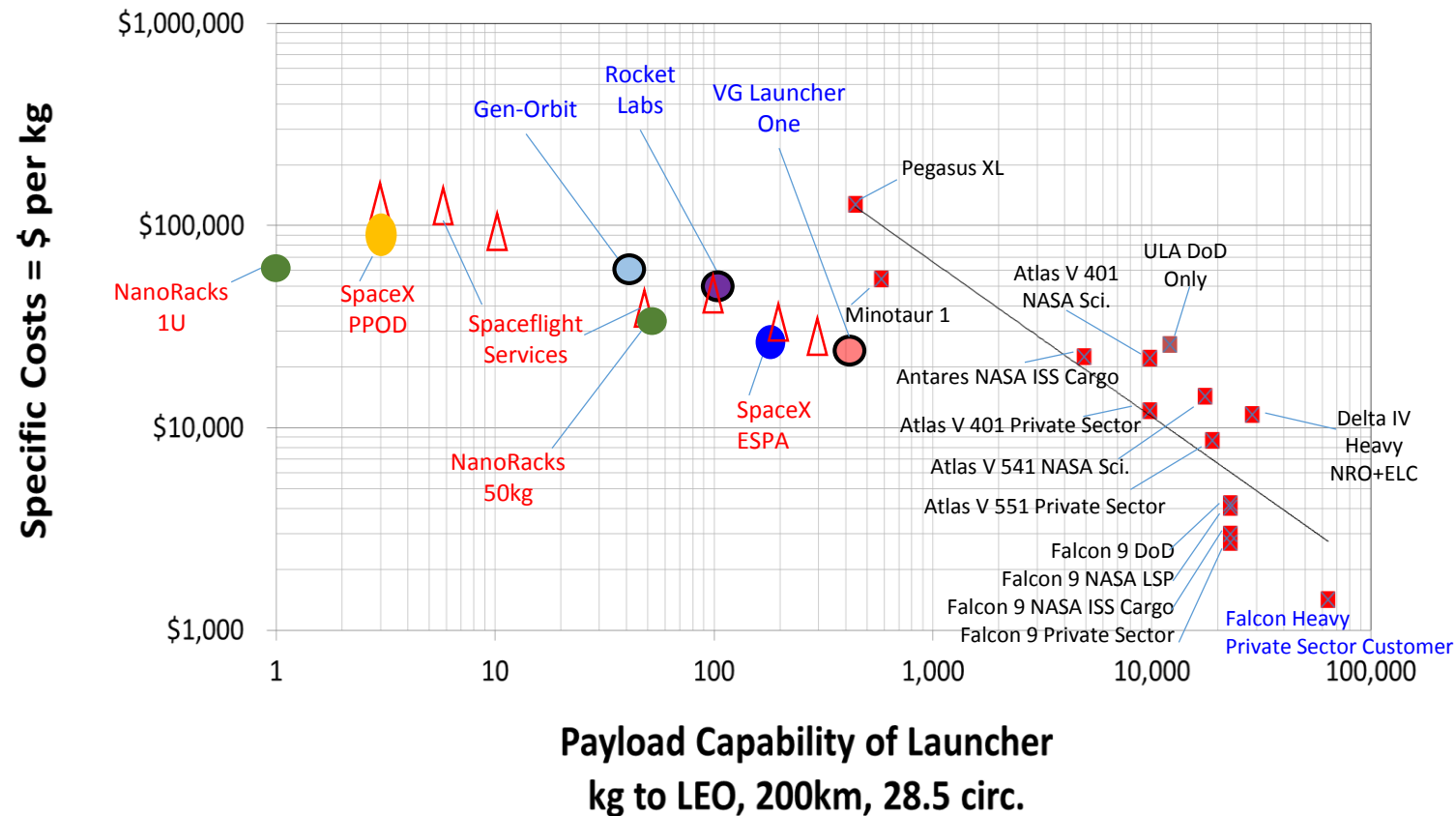
Recent Launch Prices as \$/kg of Payload (2017\$)

With Available US Small Launch / Services + In Development

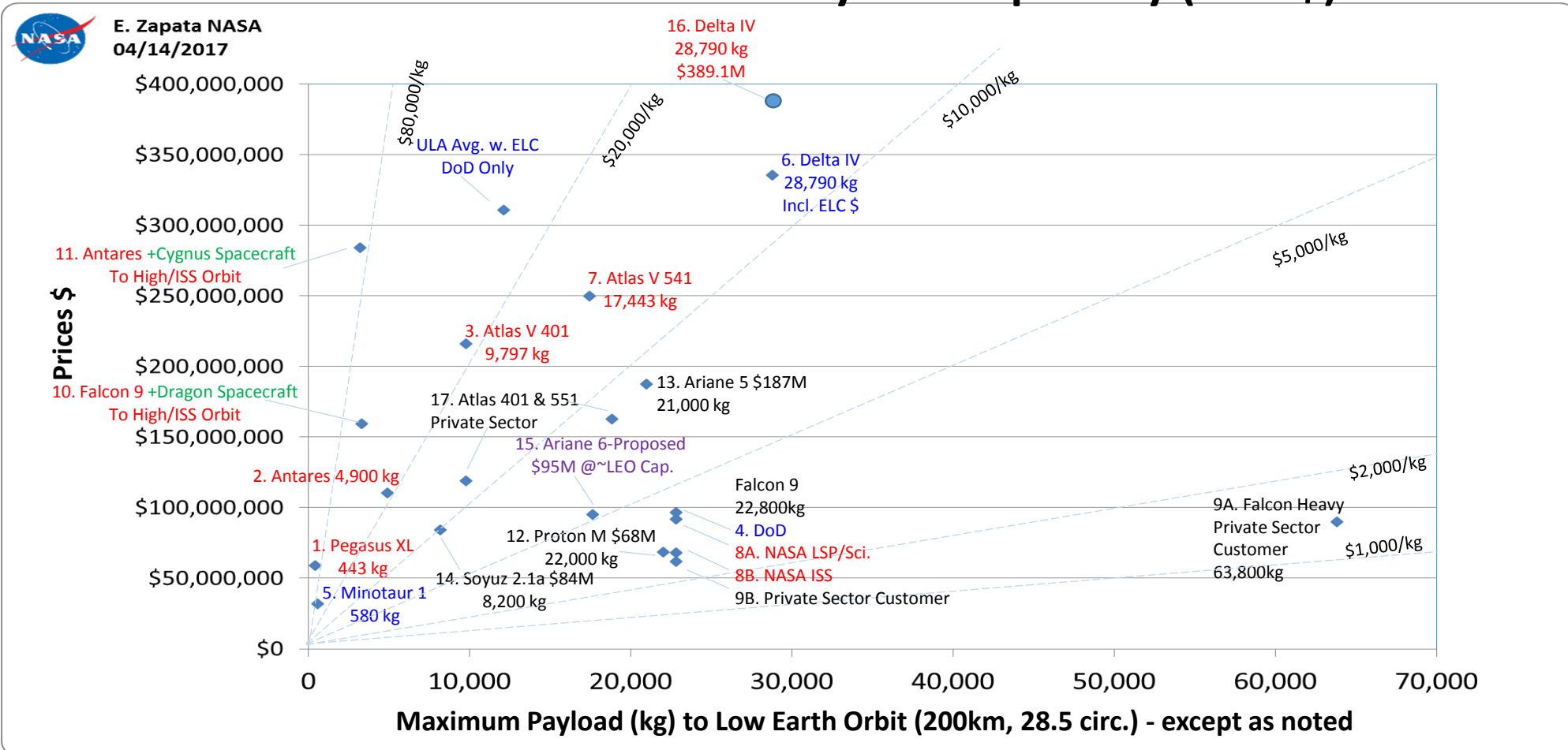
- NanoRacks as of 12/7/2015
- △ SpaceFlight Services as of 12/7/2015
- Virgin Galactic Launcher One as of 9/14/2015
- Rocket Labs as of 8/10/2015
- Generation Orbit as of 6/5/2015
- See Backup slides for data sources

NASA
E. Zapata NASA
04/16/2017

\$ Price per kg vs. Payload Capability
Recent US Launch Price Data 2017\$



Recent Launch Prices vs. Payload Capability (2017\$)



1. NASA price contracted for one 2017 launch (ICON)
2. NASA price contracted for block of launches as a service (ISS cargo, derived price, minus Cygnus Spacecraft)
3. NASA price contracted in 2010, launched in 2013 (MAVEN)
4. DoD Price contracted in 2017 for a GPS launch
5. DoD Price contracted, launched in 2013
6. Price to DoD of the launch service including the amortized EELV Launch Capabilities (ELC) contract, the yearly ELC contract amount divided evenly over the DoD only launches, for NRO
7. NASA Price contracted in 2012, each, with two launches procured together, launched in 2016 + TBD 2017
- 8A. and 8B. NASA Sci. price (8A) contracted in 2012, launched in 2016 (JASON), and (8B) NASA price contracted for block of launches as a service (ISS cargo, derived price, minus Dragon Spacecraft)
- 9A. and 9B. Prices for private sector customers

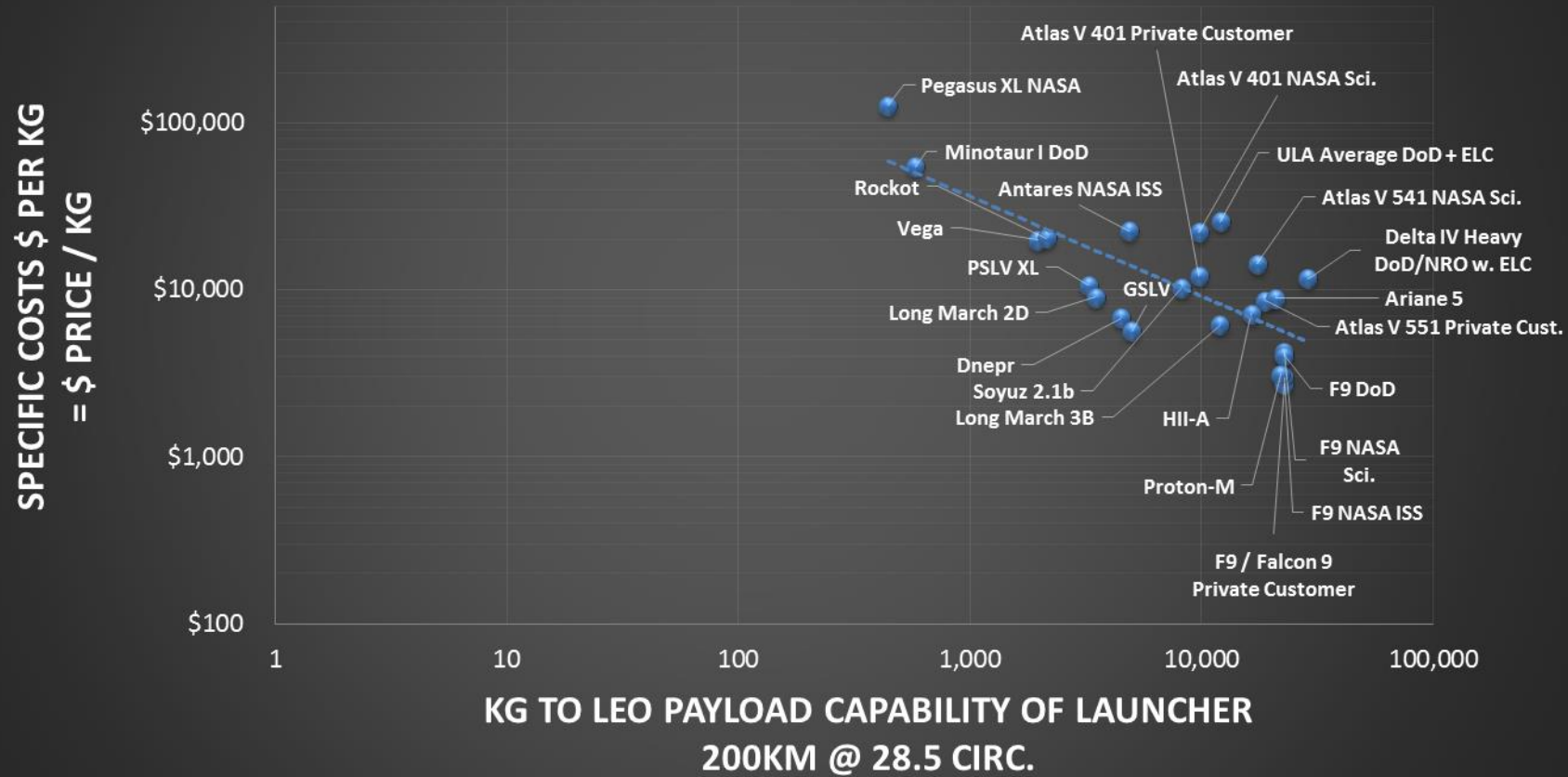
10. Price to NASA; higher orbit, plus includes providing the Dragon spacecraft for carrying / placing the customers cargo (pressurized, unpressurized, return, etc.)
11. Price to NASA; higher orbit, plus includes providing the Cygnus spacecraft for carrying / placing the customers cargo (pressurized, disposal, etc.)
12. 13. and 14. Prices to customers from 2015 launches in the 2016 FAA launch compendium
15. Ariane 6 –Proposed, shown w. derived equivalent LEO payload capacity. See backup slide and -> <http://www.spaceflightnow.com/news/n1406/17airbussafra/>
16. NASA price contracted in 2015 for one 2018 launch. See backup slide.
17. Per ULA -> www.RocketBuilder.com

Global Views



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04/12/2017

\$ per Kg (2017\$) Existing Capability



Global Views

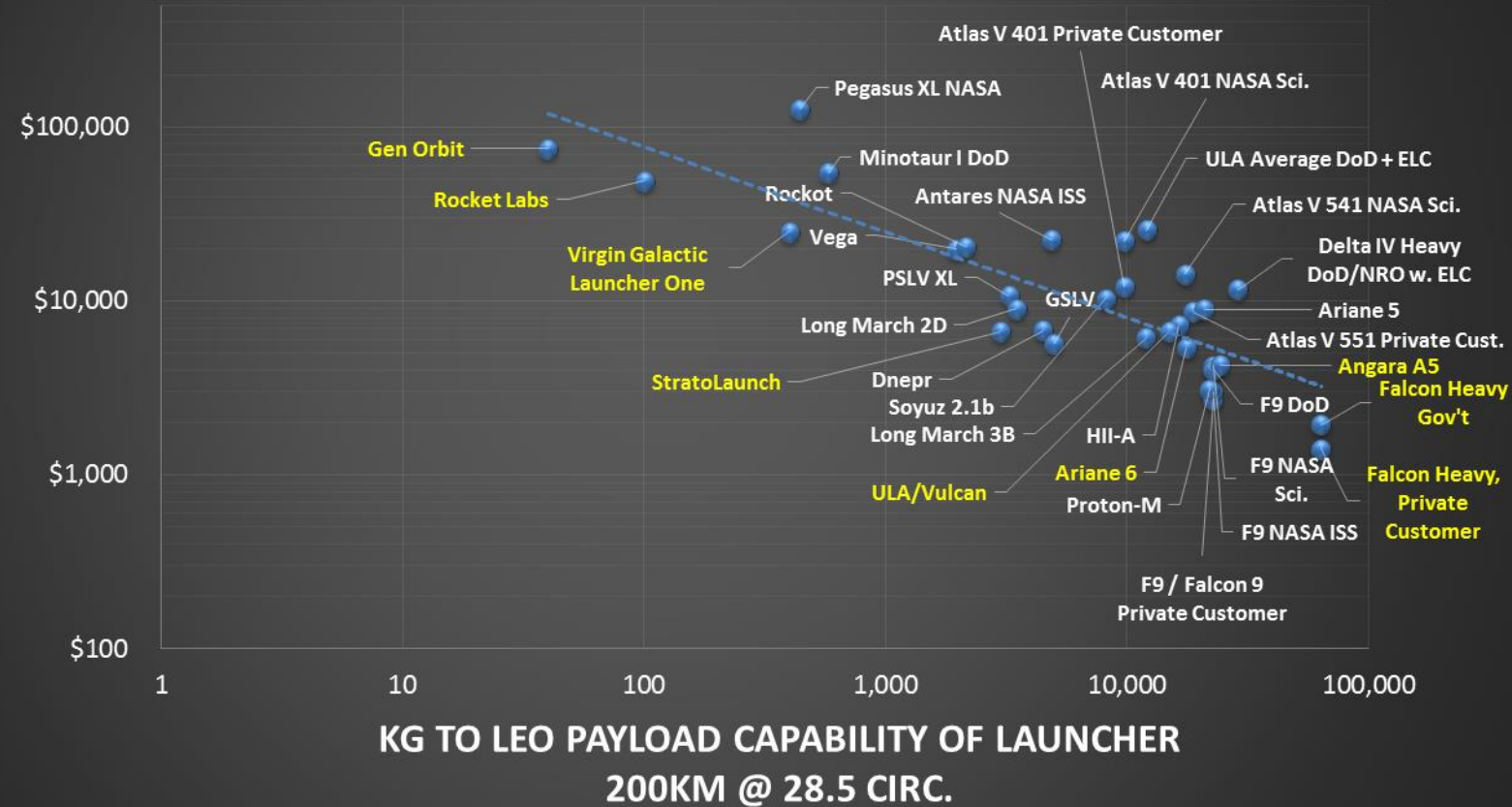


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\$ per Kg (2017\$) Existing Capability & **Planned**

Note: Proton-M and GSLV data point uncertainty high. Minotaur I data point is old, 2013. Pegasus has no announced customers after NASA in 2017. "Planned" data points are from specific company statements, but StratoLaunch, ULA/Vulcan and Angara A5 data points are derived, from less specific company statements. Falcon Heavy Gov't is estimated based on Falcon 9 Gov't price percentages above private sector price.

SPECIFIC COSTS \$ PER KG
= \$ PRICE / KG

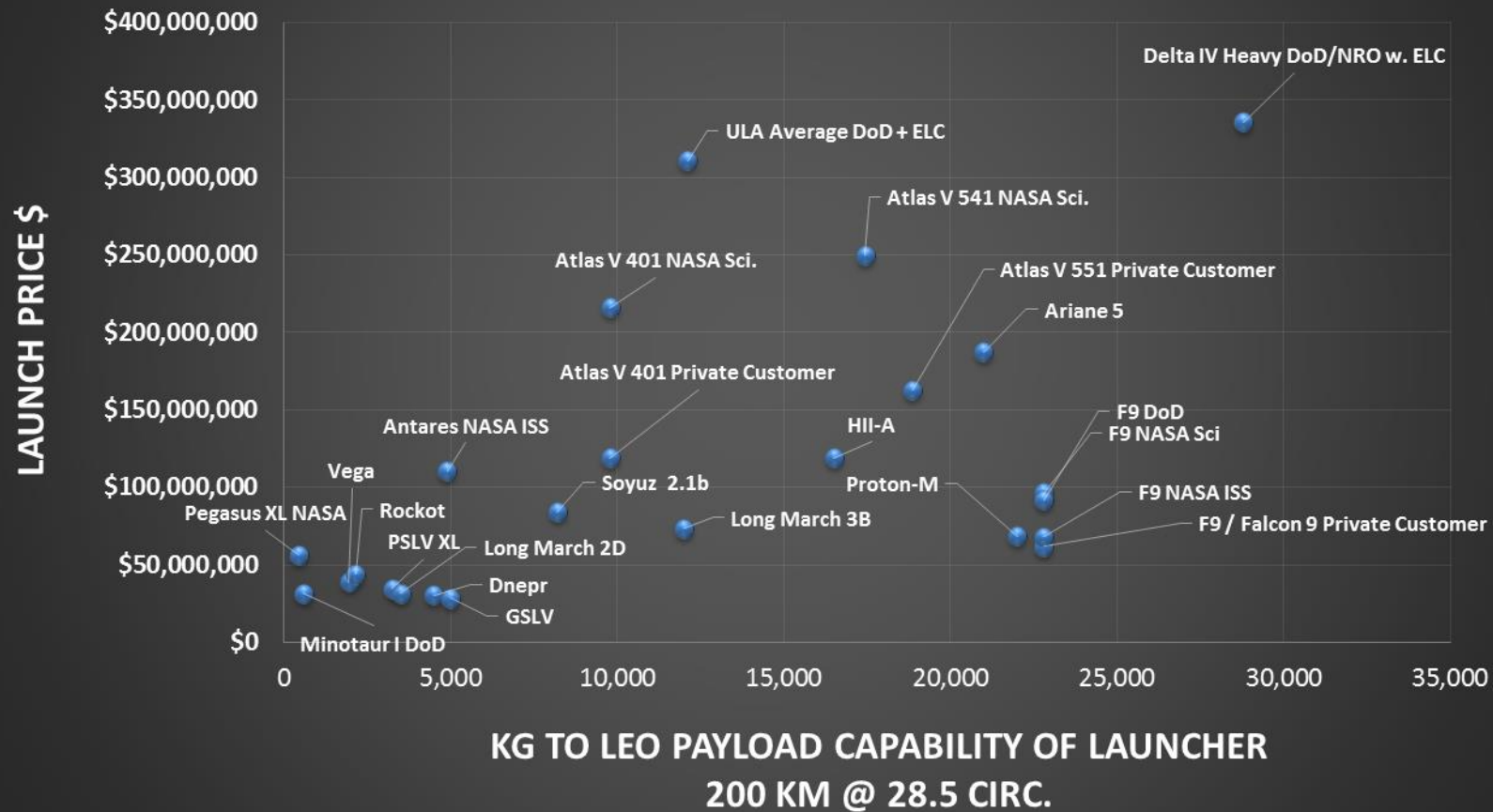


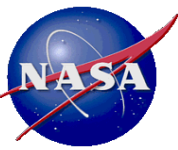
Global Views



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Launch Prices Existing Capabilities (2017 \$)

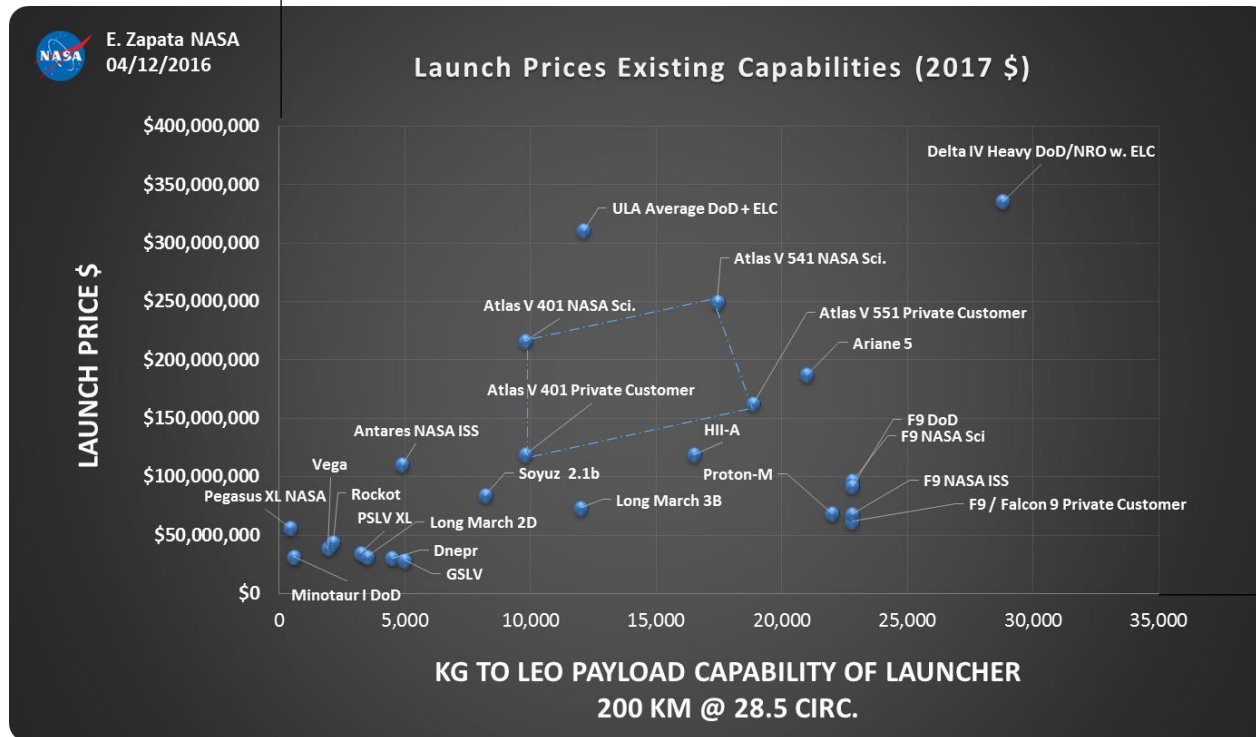




Global Views

SLS (procurement \$ only, no upper stage, + a percent of ground ops \$, no flight ops \$, IF 2 flights per year)
70,000kg->LEO
\$1,094,000,000 per Launch
(Add EUS upper stage costs for more capability to ~105t)

Falcon Heavy
63,800 kg->LEO
\$90,000,000 Price to Private Customer



Launch Systems – Multiple Measures – Especially kg per Year



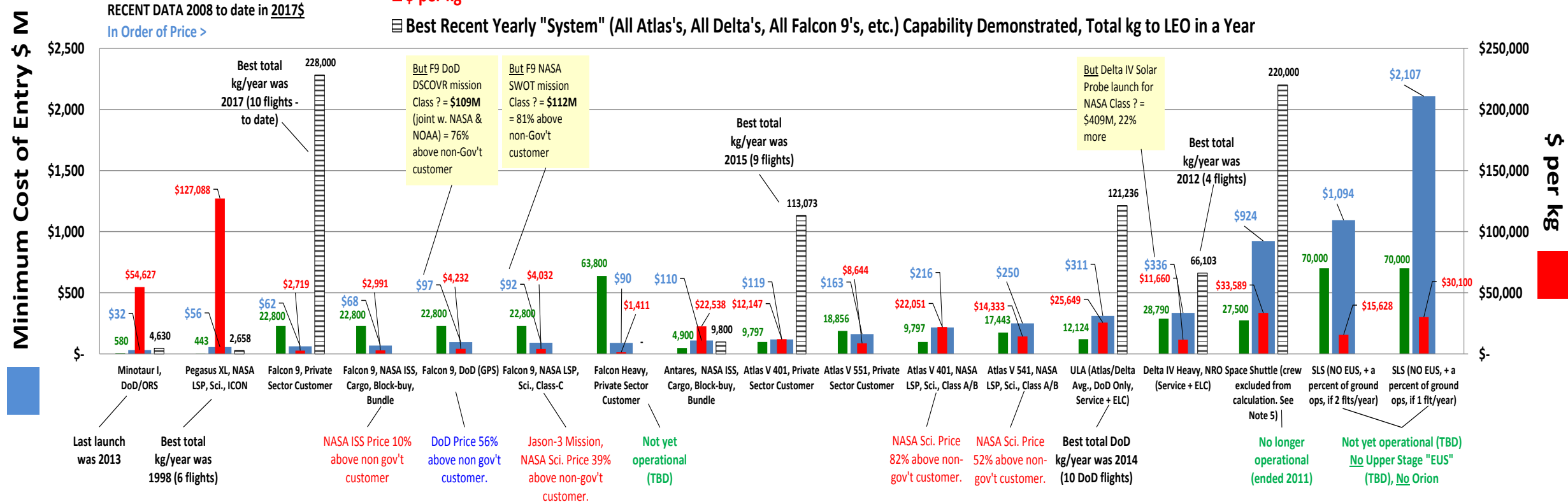
E. Zapata NASA
07/05/2017

■ Cost of Entry = Price of the Specific Launcher for that Customer / Application

■ Maximum Payload Capability of Launcher, kg to LEO, 200km/28.5 circ. (regardless of actual kg used by customer)

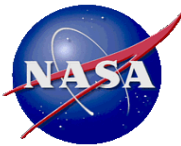
■ \$ per kg

▤ Best Recent Yearly "System" (All Atlas's, All Delta's, All Falcon 9's, etc.) Capability Demonstrated, Total kg to LEO in a Year



Trying to estimate a launch price, the cost of a launch for NASA or DoD? Ask the following, then see which data point above is most similar.

1. Who is procuring the launch?
The NASA Launch Services Program? The NASA ISS Transportation Office (Cargo)? The NASA ISS Commercial Crew Office? The DoD / Air Force? The DoD / Air Force for the National Reconnaissance Office (NRO)? A private sector customer?
2. How is the launch procured? As a block of launches, or as a single award unrelated to others? As a service (like cargo to the ISS)?
3. With what other items is the launcher being procured alongside, such as a spacecraft (Cygnus, Dragon)?
4. What is being launched? Is the launch for simpler cargo, repetitive and similar, or more complex, irreplaceable, unique? Or is it for crew?



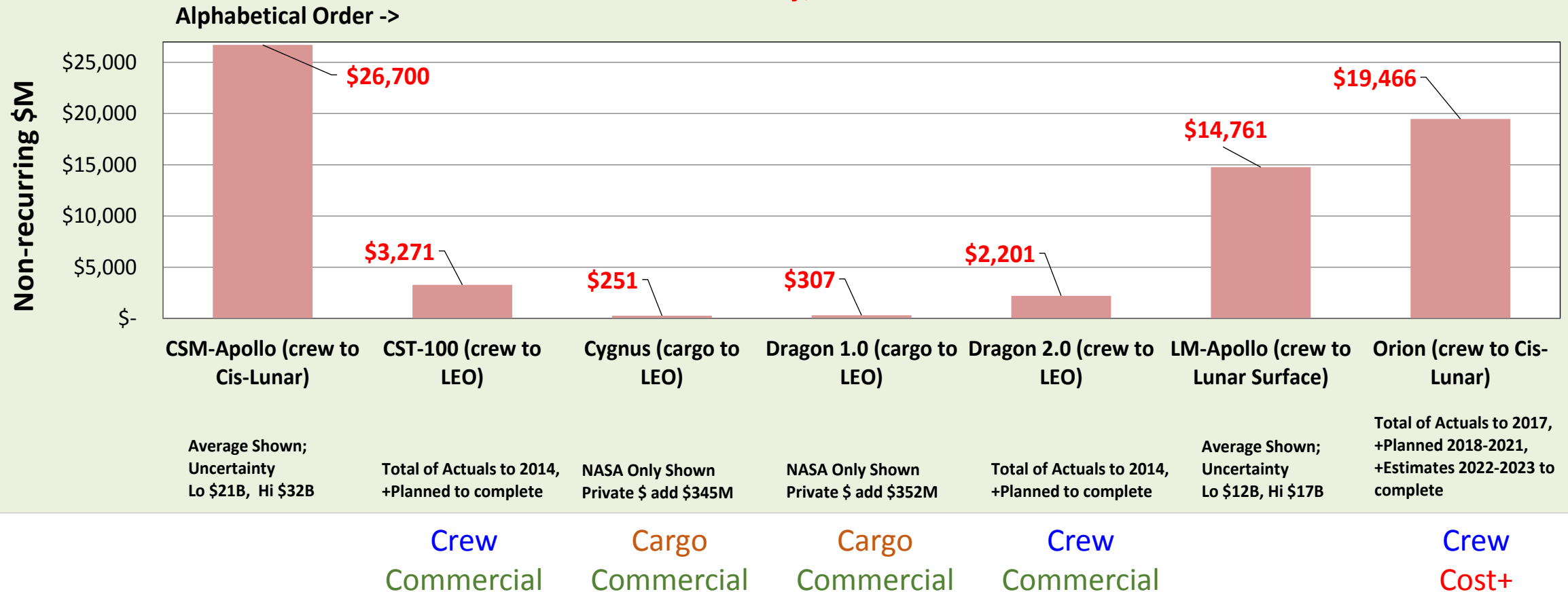
Spacecraft Costs – Development

(Costs = Price to NASA)



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Spacecraft Non-recurring NASA Development,
Procurement Only, \$M 2017\$



Spacecraft Costs – Per Unit – \$ Thru Delivery Point as Indicated

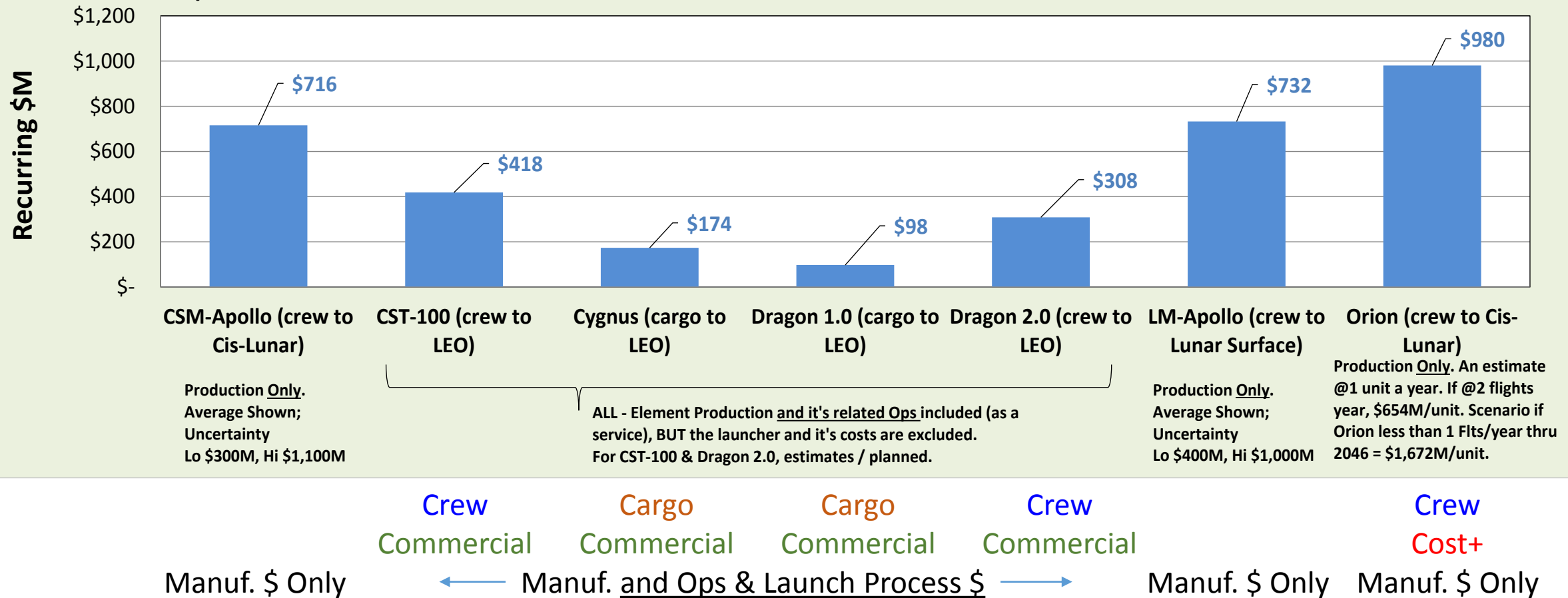
(Costs = Price to NASA)



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5/8/2017

Spacecraft Recurring Price to NASA per Unit, Procurement Only, \$M 2017\$

Alphabetical Order ->

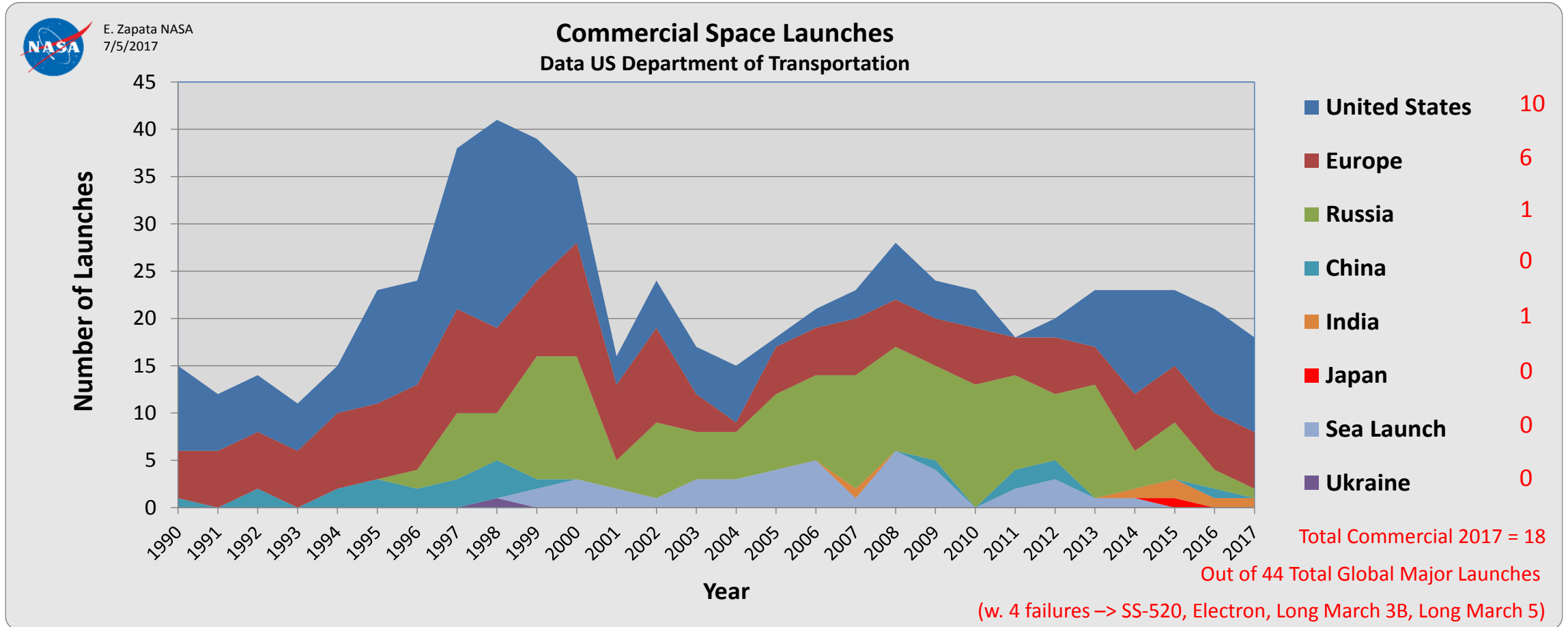


Competitiveness

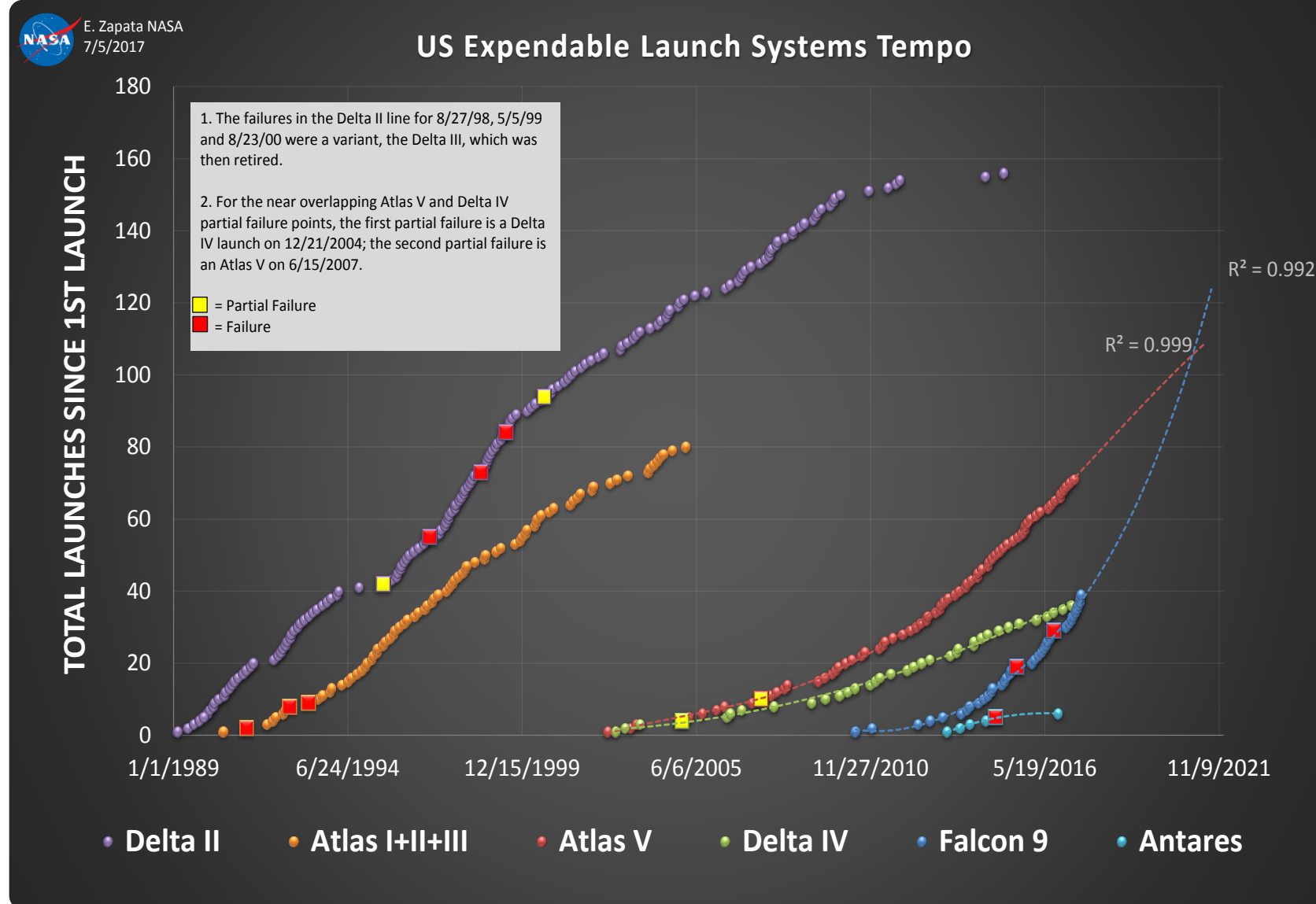
Commercial launch data through 2014 from US DOT <http://www.rita.dot.gov/bts/node/490911>

2015 -2017 data from assorted sources

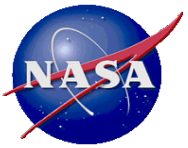
Global launch count and failures from <http://www.spacelaunchreport.com/log2017.html#stats>



Growth

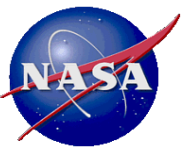


Backup



Data Sources, Small Payload Launch Options, Small Launch in Development, Other (see slides 6-7)

- As of 12/07/2015 - NanoRacks - “Commercial payloads start at \$60,000 per 1U” + volume discounts, to 50kg as advertised @ <http://nanoracks.com/resources/faq/>
 - 3U \$295,000, 6U \$545,000, 12U \$995,000, 50kg \$1,750,000, 100kg \$3,950,000, 200kg \$5,950,000, 300kg \$7,950,000 as advertised @ <http://www.spaceflightindustries.com/schedule-pricing/>
- SpaceX - secondary payload “PPOD” to LEO \$200,000-\$325,000 (=\$67,000-\$108,000/kg; from Aug. 2012, 26th Annual AIAA USU, Conference on Small Satellites)
- SpaceX – secondary payload, ESPA-class satellite weighing up to 180 kilograms would cost \$4–5 million for LEO; from August 2012, 26th Annual AIAA USU, Conference on Small Satellites (=\$22,000 to \$28,000/kg)
- As of 09/14/2015 – Virgin / Launcher One - **In development** - 400kg to LEO for \$10M (=\$25,000/kg) per <http://www.parabolicarc.com/2015/09/14/virgin-galactic-announces-capable-launcherone/>
- As of 08/10/2015 - Rocket Lab - **In development** - 100kg to LEO for \$4.9M (=\$49,000/kg) per <http://www.geekwire.com/2015/reserve-a-launch-for-your-satellite-online-rocket-lab-can-make-it-so/> albeit to a 310 mile high orbit, implying performance to LEO 200nm is more, so the “ ”
- As of 06/05/2015 - Generation Orbit - **In development** – 40kg to LEO for \$2.5M (=\$62,500/kg) per <http://www.satellitetoday.com/launch/2015/06/05/generation-orbit-gains-golauncher2-commitments-plans-golauncher-3/>
- As of 07/08/2016 – Stratolaunch / Vulcan Aerospace – **In development** – No public price statements by the company. Some early payload performance statements (6,100kg to LEO) that have since been overtaken by events. https://en.wikipedia.org/wiki/Stratolaunch_Systems



Misc.

Ariane 6 in the news:

July 2, 2014

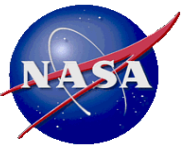
Airbus Defends Springing Last-minute Ariane 6 Design on ESA

“PARIS — The head of Airbus’ space division on July 1 said his company was forced to come up with an Ariane 6 rocket design that competed with the version approved by the European and French space agencies **because the agency version ultimately would have decimated Europe’s rocket industry.**

Testifying before the French Senate Committee on Foreign Affairs, Defense and Armed Forces, Francois Auque said the solid-fuel-dominated Ariane 6 design that the European Space Agency and the French space agency, CNES, approved in July 2013 would have attracted mainly European government customers — a market whose size would mean reducing Europe’s rocket design and production industry by two-thirds.

To avoid being decimated, he said, European rocket builders needed to be sure that the commercial market, which accounts for 90 percent of the launches of Europe’s current heavy-lift Ariane 5 vehicle, would support the new vehicle.”

<http://www.spacenews.com/article/launch-report/41117airbus-defends-springing-last-minute-ariane-6-design-on-esa>



Misc.

Delta IV Cost (Price) to NASA:

March 18, 2015

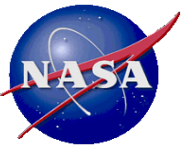
Delta 4-Heavy Selected for Launch of Solar Probe

“As expected, NASA announced its selection of the United Launch Alliance Delta 4-Heavy rocket to dispatch the Solar Probe Plus mission from Earth. Liftoff from Cape Canaveral is set for July 31, 2018, at the opening of a 20-day launch window, NASA said in a press release.

...

The launch contract's value is \$389.1 million, according to NASA.”

<http://spaceflightnow.com/2015/03/18/delta-4-heavy-selected-for-launch-of-solar-probe/>



Misc.

Falcon 9 Cost (Price) to NASA:

November 22, 2016

NASA Selects Launch Services for Global Surface Water Survey Mission

“NASA has selected Space Exploration Technologies (SpaceX) of Hawthorne, California, to provide launch services for the agency’s Surface Water and Ocean Topography ([SWOT](#)) mission. Launch is targeted for April 2021 on a SpaceX Falcon 9 rocket from Space Launch Complex 4E at Vandenberg Air Force Base in California.

The total cost for NASA to launch SWOT is approximately \$112 million.”

<https://www.nasa.gov/press-release/nasa-selects-launch-services-for-global-surface-water-survey-mission>